

**The  $\rho - \pi$  Puzzle of  $J/\psi$  and  $\psi'$  Decays****March 23, 1999**

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**Abstract**

The recent BES Collaboration data on  $\psi' \rightarrow PV$ , particularly the isospin violating mode  $\psi' \rightarrow \pi^0 \omega^0$  and finding of a finite number for  $B(\psi' \rightarrow K^{*0} \bar{K}^0)$ , enable us now to deal more precisely about the challenges to theory concerning this extraordinary and remarkable so called  $\rho - \pi$  Puzzle of  $J/\psi$  and  $\psi'$  Decays. In terms of existing data, and deploying the simplest phenomenology, measurement of  $\psi' \rightarrow \pi^+ \pi^-$  and whether a finite number for the  $K^{*+} K^-$  mode might require a significantly larger accumulation of data, remain interesting questions.

The strong suppression of  $\psi' \rightarrow \rho\pi$  and  $K^* \bar{K}$  decays is well known and has been the subject for considerable experimental and theoretical activity. No evidence is seen for  $\psi' \rightarrow \rho\pi$  in the BES group's 3.8 million  $\psi'$  event sample, in striking contrast to the case for the  $J/\psi$ , where  $J/\psi \rightarrow \rho\pi$  is the dominant decay. This conundrum is referred to as the “ $\rho\pi$ ” puzzle and remains one of the most intriguing mysteries in quarkonium physics. The BES group <sup>[1]</sup> has the largest event sample of  $\psi'$  decays thus affording it the opportunity to undertake a systematic investigation of  $\psi'$  decays to all of the lowest lying vector- plus pseudoscalar-meson (VP) final states. Of particular interest is the identification of the isospin violating mode  $\psi' \rightarrow \pi^0 \omega^0$  and the finding of a finite value for the branching ratio  $B(\psi' \rightarrow K^{*0} \bar{K}^0)$  which is likely an isospin violating VP case. These new numbers impel us by creating a “crisis” to deal in a systematic manner both theoretically and experimentally to pin down the essential nature of this so called  $\rho - \pi$  Puzzle of  $J/\psi$  and  $\psi'$  decays. Indeed interesting further but pedestrian tests appear feasible for the BES sample within a phenomenological framework, e.g. measurement of

$\psi' \rightarrow \pi^+\pi^-, \omega\eta, \rho\eta'$  and  $\rho\eta$ , though to reach for  $\psi'$  to the charged  $K^{*+}K^-$  VP mode might require a significantly larger data sample such as may be possible with the construction of a new main drift chamber MDC III and a future tau-charm factory at IHEP.

On the theoretical side, there has also been much recent activity [2]. Li, Bugg, and Zou [2] argued that final-state interactions involving the rescattering of  $a_1\rho$  and  $a_2$  into  $\rho\pi$  could be important and might interfere destructively in the case of  $\psi'$ . The possibility of a destructive interference in  $\psi'$ , though it is fortuitous, cannot be ruled out in view of Suzuki's finding [2] of the large long distance final-state interaction in  $J/\psi$  based on existing data. However, this interference model does appear to have more assumptions than predictions! Brodsky and Karliner [2] suggested that the decays  $J/\psi, \psi' \rightarrow \rho\pi$  proceed through the intrinsic charm component of the  $\rho$  wavefunction. They argue that the  $c\bar{c}$  pair in the  $|u\bar{d}c\bar{c}\rangle$  Fock state of the  $\rho^+$  has a nodeless wavefunction which gives it a larger overlap with  $J/\psi$  than  $\psi'$ . This model dramatically challenges the assumption that charmonium states necessarily decay via intermediate gluons to exclusive low mass hadrons, deploying the analogy with the  $s\bar{s}(\phi)$  case found at LEAR where there is evidence in  $p\bar{p}$  annihilation at rest of large violation of the OZI rule through gluon intermediary. However this paper is not yet characterized by experimentally checkable numbers for the charmonium system. On the subject of nodes in wave-functions, Pinsky [2] had proposed several years back that there is a node in the radial wave function for  $\psi'$ , but not for  $J/\psi$ , and that this node makes  $\psi' \rightarrow \rho\pi$  a hindered M1 transition like  $J/\psi \rightarrow \gamma\eta_c$ . However the BES measurements [3]  $\psi' \rightarrow \gamma\eta'$  leads to the ratio

$$\mathcal{Q}_{\gamma\eta'} = \frac{B(\psi(2S) \rightarrow \gamma\eta')}{B(J/\psi \rightarrow \gamma\eta')} = 0.036 \pm 0.009 \quad (1)$$

whereas Pinsky [2] relates the process  $\psi' \rightarrow \gamma\eta'$  to the hindered M1 transition  $\psi' \rightarrow \gamma\eta_c$  and predicts  $\mathcal{Q}_{\gamma\eta'} = 0.002$ , which is well below the BES measured value. Finally there is the model of Chen and Braaten [2] in which the  $c\bar{c}$  pair is in a color octet  $^3S_1$  state for  $J/\psi$ .

Hou and Soni [4] developed an earlier suggestion of Freund and Nambu [4] that the decay  $J/\psi \rightarrow \rho\pi$  is enhanced by the mixing of the  $J/\psi$  with a glueball  $\mathcal{O}$  that decays to  $\rho\pi$ . Brodsky, Lepage, and Tuan [4] (henceforth referred to as BLT) emphasized that  $J/\psi \rightarrow \rho\pi$  violates the helicity selection rules of perturbative QCD, and argued that the data requires the glueball  $\mathcal{O}$  to be fairly narrow and nearly degenerate with the  $J/\psi$ . It was however long recognized [5] that the BLT model had a ‘fly in the ointment’ in the known isospin violating decay  $J/\psi \rightarrow \pi^0\omega$ . We shall discuss below this mode in some detail. Present data from BES constrains the mass and width of the glueball to the range  $|m_{\mathcal{O}} - m_{J/\psi}| < 80$  MeV and  $4$  MeV  $< \Gamma_{\mathcal{O}} < 50$  MeV [6,7]. As stressed by Chen and Braaten [2] this mass is perhaps 700 MeV (or more) lighter than the lightest  $J^{PC} = 1^{--}$  glueball observed in lattice simulation of QCD without dynamical quarks (the “quenched” approximation) [8]. However, lattice calculations for the heavier glueball prediction may be less reliable than those

for the low mass  $J^{PC} = 0^{++}$  gluonium state, since as acknowledged by Bali et al.<sup>[8]</sup> lattice studies on the vector glueball are scarce and inconclusive, mainly because of the difficulties in constructing the corresponding lattice operators. Indeed recent QCD sum rule work also find  $m(1^{--}) \cong 3.1$  GeV(!), and a 3 GeV  $1^{--}$  glueball is quite reasonable according to Brodsky<sup>[9]</sup>.

A major problem for the Omicron  $\mathcal{O}$  gluonium explanation of the  $\rho\pi$  puzzle, as well as other serious contending models which have an underlying assumption that hadron helicity conservation HHC<sup>[10]</sup> holds at both  $J/\psi$  and  $\psi'$  (included here are the explanations of Brodsky and Karliner<sup>[2]</sup> as well as Chen and Braaten<sup>[2]</sup> which differ in details about the importance of  $D\overline{D}$  channel and end point form factor<sup>[9]</sup>), is the known relatively large decay rate for  $J/\psi \rightarrow \pi^0\omega$ <sup>[5]</sup>, the PDG branching ratio<sup>[11]</sup> is  $(4.2 \pm 0.6) \times 10^{-4}$ , approximately three times larger than the  $J/\psi \rightarrow \pi^+\pi^-$  rate. Both of these  $I=1$  decays are at first sight presumed to be due to electromagnetic decay (via a highly virtual  $\gamma(Q^2)$ ,  $Q^2 \gg 0$ ) or  $gg\gamma$ , where the helicity properties of their amplitudes are identical to the strong decay  $J/\psi \rightarrow ggg \rightarrow \rho\pi$ <sup>[9]</sup>, and thus should satisfy the requirements of PQCD helicity conservation<sup>[10]</sup>. But there is no sign of suppression due to hadron helicity conservation for  $J/\psi \rightarrow \omega\pi^0$ ! One possibility is that there are additional  $q\bar{q}g$   $I = 1$  resonances in the 3 GeV mass range which contributes to the  $\omega\pi^0$  channel (indeed the Omicron could be the  $I = 0$  member of a hybrid  $q\bar{q}g$  state at 3 GeV). But this would destroy the elegance of Hou's argument<sup>[6]</sup> on why a gluonium  $1^{--}$  should be at 3 GeV and in any case is a contrived band aid solution. Moshe Kugler<sup>[12]</sup> suggested that the large then known  $J/\psi \rightarrow \omega\pi^0$  mode could be attributed to  $\rho - \omega$  mixing. However<sup>[13]</sup> the  $\rho - \omega$  mixing model cannot give the large rate of  $J/\psi \rightarrow \omega\pi^0$  through  $J/\psi \rightarrow \rho^0\pi^0 \rightarrow \omega\pi^0$ , because experimentally the rate of  $J/\psi \rightarrow \omega\pi^0$  is as large as 0.1 times the rate of  $J/\psi \rightarrow \rho^0\pi^0$ <sup>[11]</sup>, whereas the effect of  $\rho - \omega$  mixing is only of order  $10^{-2}$  (note that, e.g. the branching ratio of  $\omega \rightarrow \pi^+\pi^-$  is about 2%). Thus Brodsky presciently suggested even in 1989<sup>[5]</sup>, that in any event it will be very important to compare these branching ratios for  $\pi^+\pi^-$ , and  $\omega^0\pi^0$  at the  $\psi'$  and off resonance.

One expects the  $J/\psi$  and  $\psi'$  mesons to decay to hadrons via 3g or for  $\omega\pi^0$  via  $\gamma$  or  $gg\gamma$ . In either case the decay proceeds via  $|\psi(0)|^2$ , where  $\psi(0)$  is the wave function at the origin in the non relativistic quark model for  $c\bar{c}$ . Thus it is reasonable to expect on the basis of perturbative QCD that for any exclusive hadronic final state  $h$  (including  $\omega\pi^0$ ), the branching fractions scale like the branching fractions in  $e^+e^-$ , to wit

$$S = 0.14B(J/\psi \rightarrow h)/B(\psi' \rightarrow h) \cong S_{e^+e^-} \cong 1. \quad (2)$$

Hence following up on Brodsky's concern<sup>[5]</sup>, it was argued<sup>[14]</sup> that an intriguing experimental measurement, if hadron helicity conservation HHC Theorem<sup>[10]</sup> is not applicable at both  $J/\psi - \psi'$  mass range, is to measure  $\psi' \rightarrow \pi^0\omega$  at the level given by the 14% rule of Eq.(2), i.e,  $0.14 \times B(J/\psi \rightarrow \omega\pi^0) \sim 0.6 \times 10^{-4}$ . The BES data<sup>[1]</sup> for  $B(\psi' \rightarrow \omega\pi^0)$  is

$(0.40 \pm 0.10 \pm 0.06) \times 10^{-4}$  and hence taking into account experimental errors, the  $\omega\pi^0$  decay is consistent with the 14% rule (2). It would appear that only one final test is needed to shut out the relevance of HHC <sup>[10]</sup> for the  $J/\psi/\psi'$  mass region, and this is to measure the  $\psi' \rightarrow \pi^+\pi^-$  rate, which could be about three times smaller than  $\psi' \rightarrow \omega\pi^0$ , if we believe in the analogy with  $J/\psi \rightarrow \pi^+\pi^-$ . Note also the stringent bound on <sup>[11]</sup>  $B(J/\psi \rightarrow \phi\pi^0)$  as well as the upper limit for  $B(\psi' \rightarrow \phi\pi^0)$  of  $< 0.66 \times 10^{-5}$  (90% C.L.) in BES data <sup>[1]</sup> for these companion isospin violating decays. The situation here can however be understood in terms of the analysis of Haber & Perrier <sup>[15]</sup>, namely the reduced branching ratio  $\tilde{B}(J/\psi \rightarrow PV) = B(J/\psi \rightarrow PV)/p_V^3$  ( $p_V$  is momentum of vector meson in the center of mass) satisfy

$$\frac{\tilde{B}(J/\psi \rightarrow \pi^0\phi)}{\tilde{B}(J/\psi \rightarrow \pi^0\omega)} = \left[ \frac{1 - (2)^{\frac{1}{2}} \tan \theta_V}{\tan \theta_V + (2)^{\frac{1}{2}}} \right] \quad (3)$$

for nonet symmetry. If  $\phi-\omega$  are assumed to be ideally mixed as well [ $\tan \theta_V = (1/2)^{\frac{1}{2}}$ ], then  $B(J/\psi \rightarrow \pi^0\phi)$  vanishes. A similar situation can be anticipated for  $B(\psi' \rightarrow \pi^0\phi)$ .

We must not however rush to judgment on the demise of HHC for  $J/\psi/\psi'$ . First, the experimental ‘support’ for HHC in  $J/\psi \rightarrow \omega\pi^0$  by Baltrusaistis et al. <sup>[16]</sup> is a qualitative one based on its steeper drop in form factor from  $q^2 = 0$  to  $q^2 = m_{J/\psi}^2$  when compared with analogous  $\pi\pi$  form factor measured in  $J/\psi \rightarrow \pi^+\pi^-$ . Pakvasa <sup>[17]</sup> pointed out that it is known from the Sutherland Theorem based on PCAC that the isospin violating decay  $\eta^0 \rightarrow \pi^+\pi^-\pi^0$  vanishes for an electromagnetic intermediary, but rather is due to  $m_d - m_u$  current quark mass difference effect. In the present context  $J/\psi \rightarrow \pi^0\omega$  might have a dominant decay amplitude  $\sim (m_d - m_u)/m_c \cong \alpha/\pi$  <sup>[9]</sup> from this ‘strong’ effect not covered by HHC, and the electromagnetic intermediary  $\gamma$ ,  $gg$   $\gamma$  governed by HHC to be  $(\alpha/\pi) \times$  [helicity suppression]. Perhaps we are seeing the former mechanism at work in the decays  $J/\psi, \psi' \rightarrow \omega\pi^0$ . Our understanding of  $m_u - m_d$  effect in charmonium decays is however clearly inadequate still. Though like Brodsky and Karliner <sup>[2]</sup> (in a different context) we have dispensed with the  $\gamma^*$ ,  $gg$   $\gamma$ ,  $3g$  contributions in  $\psi'$  and  $J/\psi$  decays to  $\omega\pi^0$ , it remains a mystery why for instance isospin violating  $\psi' \rightarrow \rho\pi$  decay has not been seen through this mechanism <sup>[9]</sup>. Indeed the limit <sup>[1]</sup> on  $\psi' \rightarrow \omega\eta < 0.26 \times 10^{-4}$  (90% C.L.) when compared with  $\psi' \rightarrow \omega\pi^0$  rate may pose another example of this difficulty. Hence the present note is to be regarded as a stimulus for further theoretical study on the needed physical idea to complete our understanding. Setting aside this obstacle, it is amusing that a consistent picture can be sketched for all presently known  $\psi' \rightarrow PV$  decays <sup>[1]</sup> in which HHC is valid at both  $J/\psi, \psi'$  mass scales for the strong  $3g$  intermediary decays, based on the BLT model <sup>[4]</sup> supplemented by recent work <sup>[6]</sup>.

Seiden, Sadrozinski, and Haber <sup>[18]</sup> presented a general phenomenological parametrization of amplitudes for  $J/\psi \rightarrow P + V$  in their Table IV. We adapt their analysis for  $\psi' \rightarrow P + V$  using their notation. Hence  $g =$  strong

singly disconnected SOZI amplitude with 3 gluons exchanged,  $e$  is the “electromagnetic” amplitude which may actually arise from the  $(m_d - m_u)$  effect discussed above but expected to be comparable to the usual electromagnetic strength,  $r$  the doubly disconnected DOZI suppression factor breaking nonet symmetry. The  $SU(3)$  violation is accounted for by a factor  $(1 - s)$  for every strange quark contributing to  $g$ , a factor  $(1 - s_p)$  for a strange pseudoscalar contributing to  $r$ , a factor  $(1 - s_v)$  for a strange vector contributing to  $r$ , and a factor  $(1 - s_e)$ , if relevant, for a strange quark contributing to  $e$ . One crucial ingredient to the analysis is the quark content of the  $\eta$  and  $\eta'$ . We shall argue below that the BES data <sup>[1]</sup> are in fact consistent with the assumption that the dominant part of the  $\eta$  and  $\eta'$  wavefunctions consists solely of  $u\bar{u}$ ,  $d\bar{d}$ , and  $s\bar{s}$ . It has been known for sometime <sup>[19]</sup>, that the  $c\bar{c}$  contribution to  $\eta$  and  $\eta'$  is miniscule. Following <sup>[18]</sup>, we write

$$\begin{aligned}\eta &= X_\eta |u\bar{u} + d\bar{d}\rangle / 2^{1/2} + Y_\eta |s\bar{s}\rangle \\ \eta' &= X_{\eta'} |u\bar{u} + d\bar{d}\rangle / 2^{1/2} + Y_{\eta'} |s\bar{s}\rangle\end{aligned}\tag{4}$$

and take their approximate values for the  $X$ 's and  $Y$ 's extracted from the two photon width of the  $\eta, \eta'$ , to wit

$$\begin{aligned}X_\eta &= 0.8, Y_\eta = -0.6 \\ X_{\eta'} &= 0.6, Y_{\eta'} = 0.8\end{aligned}\tag{5}$$

For  $J/\psi \rightarrow P + V$ ,  $s$  is small  $\sim 10 - 20\%$  of  $g$  and  $r \sim 0.15$ ; we shall assume the same for  $\psi' \rightarrow P + V$ . Indeed  $r$ ,  $s$ ,  $s_p$ , and  $s_v$  are all small numbers <sup>[18]</sup> for  $J/\psi \rightarrow P + V$ . It seems reasonable, given the preliminary nature of the BES data <sup>[1]</sup> for  $\psi' \rightarrow P + V$ , to make the same small number assumption here. Where needed, and for definiteness, we take

$$s_e = s_v = s_p = s = 0.15\tag{6}$$

in rough accord with expectations in  $J/\psi \rightarrow P + V$  <sup>[18]</sup>.

The analysis proceeds as follows. First  $\psi' \rightarrow \rho\pi$  has not been seen, so each of  $\rho^+\pi^-, \rho^0\pi^0, \rho^-\pi^+$  with amplitude  $g + e$ , must satisfy

$$g + e \cong 0, \text{ or } g \cong -e.\tag{7}$$

This leads to the remarkable conclusion that  $\psi' \rightarrow \rho\pi$ , via 3 gluon strong (3g) decay is suppressed to the usual electromagnetic transition level  $\sim \alpha/\pi$  in amplitude strength. Hence Brodsky-Lepage HHC Theorem <sup>[10]</sup> appears to work for  $\psi' \rightarrow \rho\pi$  strong (3g) decay, and furthermore Eq.(7) gives us a concrete measure of the magnitude of such helicity suppression. If we ignore small  $s$ ,  $s_e$  contributions, then for  $\psi' \rightarrow K^*\bar{K}$  each of  $K^{*+}K^-, K^{*-}K^+$  has amplitude

$$g(1 - s) + e(1 + s_e) \cong g + e \cong 0\tag{8}$$

which is of course consistent with existing  $\psi' \rightarrow K^{*+}K^-$  upper limit <sup>[1]</sup>. For  $K^{*0}\bar{K}^0, \bar{K}^{*0}K^0$  decay of  $\psi'$ , the amplitude for each is

$$g(1-s) - e(2-s_e) \cong -3e. \quad (9)$$

This is consistent with finite BES number for  $\psi' \rightarrow K^{*0}\overline{K}^0$ ,  $B(\psi' \rightarrow K^{*0}\overline{K}^0) = (0.84 \pm 0.24 \pm 0.16) \times 10^{-4}$  [1]. The central value is a little higher than the branching ratio for  $\psi' \rightarrow \pi^0\omega$  which has also amplitude  $3e$ . But within errors the two numbers are consistent; besides Eq. (7) is only approximate  $|g|$  may still be slightly larger than  $|e|$  leading ultimately to a finite branching ratio for  $\psi' \rightarrow \rho\pi$ . To put in some numbers and give  $\psi' \rightarrow K^{*+}K^-$  a target estimate to shoot for, let us take  $s = s_e = 0.15$  for SU(3) breaking effects and use the expressions given on left hand side of (9) with the same phase space for charged and neutral members of  $K^*\overline{K}$ . We have [using the central value for  $B(\psi' \rightarrow K^{*0}\overline{K}^0)$ ].

$$B(\psi' \rightarrow K^{*+}K^-) = 1.008 \times 10^{-6} \quad (10)$$

Assuming  $g + e = 0$ , and ignoring the small  $s_p$  contribution (with phase space factor  $p_{\omega\eta}^3/p_{\omega\eta'}^3 = 1.182$ ), we have from Seiden et al. [18] Table IV adapted to  $\psi'$  and Eq. (5) using the central value for the branching ratio  $B(\psi' \rightarrow \omega\eta)$  [1]  $= (7.9 \pm 3.6 \pm 1.5) \times 10^{-5}$

$$B(\psi' \rightarrow \omega\eta) = (0.097) \times 10^{-4}. \quad (11)$$

This is still consistent with the BES upper limit [1] for  $B(\psi' \rightarrow \omega\eta) < 0.26 \times 10^{-4}$ . We shall not make estimates for  $\psi' \rightarrow \phi\eta'$  from the known experimental number for  $\psi' \rightarrow \phi\eta$ , because as seen from Seiden et al. [18] the theoretical expressions here has the full gamut of parameters ( $g, s, s_e, s_v, r, e, s_p, X, Y$ ). It would be easy but not particularly illuminating to obtain a branching fraction for  $\psi' \rightarrow \phi\eta'$  compatible with the current experimental limit by adjusting the many parameters available in this case. The ‘electromagnetic’ transitions  $\psi' \rightarrow \rho^0\eta, \rho^0\eta'$ , where amplitudes [18] are respectively  $3eX_\eta$  and  $3eX_{\eta'}$ , can be related to the known  $\psi' \rightarrow \omega\pi^0$  rate with amplitude  $3e$  using Eq. (5). Taking the phase space factors into account [ $p_{\rho\eta}^3/p_{\omega\pi^0}^3 = 0.935$  and  $p_{\rho^0\eta'}^3/p_{\omega\pi^0}^3 = 0.793$ ] and again using the central experimental value for  $\psi' \rightarrow \omega\pi^0$  we have

$$B(\psi' \rightarrow \rho^0\eta) = 0.239 \times 10^{-4}, B(\psi' \rightarrow \rho^0\eta') = 0.115 \times 10^{-4}. \quad (12)$$

These results are quite consistent with BES values [1] that  $B(\psi' \rightarrow \rho^0\eta) = (0.21 \pm 0.11 \pm 0.05) \times 10^{-4}$  and  $B(\psi' \rightarrow \rho^0\eta') < 0.3 \times 10^{-4}$  (90% C.L.). The prediction of Eq. (10) may require a larger sample of  $\psi'$  than the 3.8 million currently available. This may be feasible with the construction of MDC III and a future tau-charm factory. We have not discussed the  $\psi' \rightarrow \gamma\eta, \gamma\eta'$  modes of BES [1] because even though of the VP type, they involve an external  $\gamma$  which is not covered by the hadron helicity conservation HHC theorem of Brodsky-Lepage [10] central to our discussion.

To summarize, amongst the models proposed to explain the strong suppression in the  $\rho\pi$ , and  $K^*\overline{K}$  channel with some claim to a quantitative basis, the  $J/\psi - \mathcal{O}$  mixing model [4,6] appears to survive the latest results, except

for isospin violating PV modes. This model requires the  $\mathcal{O}$  mass to be quite near the  $J/\psi$  and to have a substantial decay width to two-body VP meson states, as particularly emphasized by BLT [4]. Although searches for this state in an  $e^+e^- \rightarrow \rho\pi$  scan near the  $J/\psi$  mass [7] and in  $\psi' \rightarrow \pi^+\pi^-\rho\pi$  decays have been negative, they have not provided very severe restrictions on the properties of the  $\mathcal{O}$ . A better  $\mathcal{O}$  search strategy may be needed. However, we have already seen from an analysis of the preliminary BES  $\psi'$  data for PV, that within this model framework, significant insights into hadronic physics have been obtained, in particular the strength of the HHC suppression [10] to electromagnetic level at  $\psi'$  and a new departure in the understanding of isospin violating decays of  $J/\psi, \psi' \rightarrow \omega\pi^0$ , which however demands further study at a fundamental level.

Remarks (i) The  $\psi' \rightarrow VT$  final states have been measured [20] and found to be suppressed by a factor of at least three compared to the expectations of Eq. (2). Since hadronic VT decays conserve HHC [21], some other mechanism must be responsible for this (possibly mild) suppression in the BLT model [4,6] and that of Chen and Braaten [2]. This pattern can be explained by also taking into account the orbital-angular-momentum selection rule for exclusive amplitudes in perturbative QCD [22] and is under study by Chen and Braaten. The Brodsky and Karliner model [2,9] can account for comparable suppression of both VT and VP modes since the tensor mesons here could have an appreciable intrinsic charm content. There is however a general belief that intrinsic charm content of low lying V, T mesons is small [23]. (ii) Though the models of BLT [4,6] as described here and Chen and Braaten [2] have predictions for  $\psi' \rightarrow \omega\pi$ , in order of magnitude agreement with existing data [1], they are based on the phenomenological treatment of Ref. [18] rather than a fundamental understanding of this isospin violating mode in the context of HHC, which remains a shared concern with the Brodsky and Karliner model [2] also. Furthermore, the need for Chen and Braaten [2] to invoke  $c\bar{c}$  color octet  $^3S_1$  contribution to  $J/\psi$  could be a dubious assumption, since Kroll [24] has arguments on why, for some exclusive  $J/\psi$  decays at least, the color octet contribution is an  $O(v^2/c^2)$  effect and hence negligible ( $< 12\%$  or so). Mahiko Suzuki [2] in his very thorough paper demonstrated that the existing data [11] on  $J/\psi \rightarrow \omega\pi^0, \rho\pi, K^*\bar{K}$  assuming that these decays are mediated by conventional  $\gamma^*$  and  $3g$  respectively, would lead to the uncomfortable situation of a large relative phase nearly  $90^\circ$  between the three-gluon and the one-photon amplitude. Hence he is pessimistic about extracting meaningful information on B-meson decay (presumably at the future B-factory facilities) on the parameters of the fundamental interactions here. Indeed he has gone further [25] to show that the large phase problem (and possible resolution of the puzzle) may rest with measurement of  $e^+e^- \rightarrow \gamma \rightarrow \pi^+\pi^-$  and  $e^+e^- \rightarrow \gamma \rightarrow K^+K^-$  off the  $J/\psi$  without recourse to theory. However construction of MDC III and a future tau-charm factory may be needed to obtain this decisive measurement. We agree with Suzuki that a high priority of future  $e^+e^-$  facilities, e.g. the  $5 \times 10^7 J/\psi$  events expected from the

BES upgrade/MDC III, is the high precision remeasurement of the  $J/\psi$  decay branchings, particularly for  $\rho\pi$ ,  $K^*\overline{K}$ , and  $\omega\pi^0$ . (iii) Though it is hoped that eventually lattice gauge work would provide accurate prediction of the width of gluonium states like the Omicron, we note that the limit currently <sup>[6,7]</sup> set on Omicron width  $\Gamma < 50$  MeV is already a severe one. At round 3.1 GeV a 3g glueball cannot be too narrow <sup>[9]</sup>. Hence, we urge renewed effort at BES upgrade/MDC III to continue the search for the Omicron vector glueball by a scan of the  $J/\psi$  resonance. Remember that the HHC theorem <sup>[10]</sup> was developed with very minimal assumptions from perturbative QCD. If it should prove to be invalid at the  $J/\psi$  and  $\psi'$  mass range, the validity of Eq. (2) can also be questioned.

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